

PROPERTIES AND COMPOSITION OF JET FUELS
DERIVED FROM ALTERNATE ENERGY SOURCES
PART I. BACKGROUND AND N-ALKANE CONTENT

ROBERT N. HAZLETT AND JAMES M. HALL

Naval Research Laboratory
Washington, D. C. 20375

JEFFREY SOLASH

Naval Air Propulsion Test Center
Trenton, New Jersey 08628

INTRODUCTION

In the current climate of dwindling domestic production of petroleum, increased importing of petroleum, potential oil embargoes, and escalating prices, the Department of Defense has begun significant new fuels programs. These programs are evaluating the military potential of liquid transportation fluids derived from alternate fossil fuels - shale oil, tar sands and coal. Of major import to the U.S. Navy are fuels used primarily for aircraft propulsion, JP-5, and ship propulsion, Diesel Fuel Marine. The discussion in this paper will be limited to the former, jet fuel for naval aircraft. It should be noted however, that JP-5 is sometimes used as a substitute ship propulsion fuel.

CRITICAL PROPERTIES OF JET FUEL .

JP-5 must meet many stringent requirements if satisfactory performance in aircraft and fuel handling and storage systems is to be attained (1). In considering JP-5 derived from alternate fossil fuels, several critical properties stand out. With one or two exceptions, these key properties are affected more by the chemical characteristics of the fuel than by the physical properties. The important specification requirements may be primarily controlled by elemental composition, the amounts of each of the hydrocarbon classes - paraffin, naphthene, aromatic, olefin - or by specific chemical compounds. The critical properties are discussed briefly below.

A. Heat of Combustion - This property directly controls the range of a jet aircraft and it is desirable to maximize the value. Hydrocarbon fuels which are liquid at ambient temperatures have net heating values between 16,000 and 20,000 BTU/lb and the minimum specification limit for JP-5 is 18,300 BTU/lb (1). Martell and Angello have shown that the heat of combustion for jet fuels increases linearly with hydrogen content (2). The amounts of nitrogen and oxygen in jet fuel are negligible with respect to heat of combustion and the variation of sulfur in the allowable range of 0.0 to 0.4% would exert a maximum effect of 40 BTU/lb.

B. Freezing Point - Jet aircraft are exposed to low temperatures and the fuels must not interfere with flying operations by freezing and plugging filters. Commercial jet fuel (Jet A) has a specification requirement of -40°F maximum but that for military fuels is lower. JP-5 must freeze below -51°F because the Navy jets operate world wide as well as at higher altitudes than commercial jets. U.S. Air Force bombers require an even lower freezing point, -72°F maximum, since long flights at high altitudes permit the fuel to reach lower temperatures. It has not been practical to make JP-5 from some petroleum crudes because the freezing point cannot be met along with the required flash point. Dimitroff et al (3) examined the influence of composition on freezing point of several types of fuels. They found the saturate fraction of a fuel usually exerted the greatest effect on freezing point but the aromatic fraction seemed to be important in some cases.

C. Flash Point - The Navy requires a high flash point for all fuels carried onboard ships except for a small amount of aviation gasoline which is carried on some aircraft carriers. The Avgas is stored in an armored box in the center of the carrier and air/fuel vapors are minimized in the storage tanks by using a water displacement system. JP-5, which is stored in the wing tanks (flush with the hull), has a minimum flash point of 140°F in order to reduce the hazard from this and other exposure situations. The flash point of a mixture such as a fuel is controlled by the quantity and volatility of the front ends (4). The flash point and other flammability properties of some alternate jet fuels is considered in another paper at this Symposium (5).

D. Combustion Properties - Jet engines give high combustion efficiencies (98-100%) for conversion of fuel to CO₂ and H₂O. Other combustion characteristics can be deficient under such conditions, however. Flame radiation to the combustor walls can raise the temperature of the walls above desired levels (6,7). Soot deposition can also affect combustor wall temperatures. Smoke in the exhaust must be controlled both for military and environmental reasons.

The flame radiation, soot deposition, and smoke production may be closely related chemically. These three properties of a jet fuel are controlled by passing a simple wick burning test, the smoke point, or a slightly more complicated burner test, the luminometer number. The minimum smoke point for JP-5 is 19 mm and the minimum luminometer number is 50.

A secondary control on combustion properties is obtained by limiting the aromatic content to 25% (1). Condensed polynuclear aromatics are significantly more detrimental to smoke point than monocyclics (8).

E. Thermal Oxidation Stability - Jet fuel cools several systems in a jet aircraft. In a subsonic plane, the major heat load comes from the engine lubricant but for aircraft flying faster than Mach 2.2, the structure must also be cooled. The ability of a fuel to withstand this thermal stress is the most critical fuel property for high speed aircraft (9).

Degradation of the fuel is stimulated by the dissolved oxygen present in equilibrium with air (50-70 mg/l). Poor fuels form solids which coat heat exchanger surfaces and/or plug combustor nozzles. The Jet Fuel Thermal Oxidation Tester estimates these two properties by examining varnish formation on a heated metal tube and measuring the pressure drop through a filter. A satisfactory fuel passes a 2 1/2 hr test at 500°F.

Little research has been reported on the effect of chemical structure on thermal oxidation stability at 500°F but Taylor has reported on tests in the 200-400°F temperature range. He found that olefins, particularly multifunctional ones, increased deposit formation (10). At 275°F, 10 wt % indene in decane increased deposit formation 39-fold but some other aromatics decreased the deposit rate. Some sulfides and disulfides enhance deposit formation at concentrations as low as 1000 ppm sulfur (11) and nitrogen compounds also participate in deposit formation (12).

F. Gum Formation - The low temperature stability of JP-5 is estimated by the Existent Gum Test. A maximum of 7.0 mg/100 ml gum is allowed in this test. Schwartz et al. have found for gasoline that sulfur compounds are the most significant participants in gum formation but that nitrogen compounds, indanes, tetralins and olefins are also involved (13).

PROPERTIES OF ALTERNATE JET FUELS

Jet fuels made from oil shale, tar sands and coal were examined in this study. A brief outline of the processes involved in production of the fuels are listed in

Table I. Further information on processing and fuel properties can be found in another paper in this symposium (14) and in the references cited in Table I.

Table II lists the properties of the fuels pertinent to this paper. The Laramie Energy Research Center in-situ shale fuels were not produced to meet the JP-5 specs but had a boiling range (350-550°F) similar to JP-5. Since only limited amounts of the LERC samples were available, complete specification tests were not run. The discussion which follows compares, where possible, the alternate fuel properties with petroleum jet fuel properties taken from the literature. The effect of composition on properties is also described.

A. Heat of Combustion - The heat of combustion of alternate fuels is plotted in Figure 1 versus percent hydrogen. The graph shows data for the five COED, the tar sand, and the Paraho shale oil fuels. The line on this graph is curve D in Figure 3 of reference (2) and is based on 41 jet fuels derived from petroleum. The alternate fuel data fit the curve very well. The three COED fuels with high aromatic contents fall to the left. COED-1 and COED-5 fall slightly below the JP-5 requirement of 18,300 BTU/lb. Decreasing the aromatic content from about 25% to 5% (COED-1 to COED-3 or COED-2 to COED-4) increases the heat of combustion about 90 BTU/lb. The tar sands and Paraho shale fuels have higher heating values than the COED samples with similar aromatic contents. We feel this is due to a high naphthene content in the coal fuels, an expected consequence of hydrogenation of the highly aromatic syncrude obtained by coal pyrolysis (21).

B. Freezing Point/Flash Point - Most of the alternate fuel samples met the flash point requirement for JP-5. The flash point can be changed usually by the adjustment of the initial boiling point. The freezing point of several of the alternate jet fuels was too high, however. The freezing point/flash point relationships for the five COED (C-1 to C-5), tar sands (TS), and Paraho shale oil (OS) are depicted in Figure 2. No consistent pattern is evident for these fuels.

For comparison, the properties of 29 petroleum derived jet fuels are also shown on the graph. These latter fuels, which were part of the Coordinating Research Council (CRC)-Air Force (AF) fuel bank (22), did not meet all specifications in some cases. Examination of the CRC fuels is useful, however, to see the wide range in freezing points encountered for fuels with similar flash points. In Figure 2, the display is simplified by grouping the fuels by 10°F intervals for flash point. As an example, four petroleum derived fuels had flash points between 161 and 170°F. The freezing points for these same fuels were -26, -32, -62 and <-76°F. One alternate fuel sample, COED-3 had a flash point in this range and it had a freezing point of -58°F.

It is noteworthy that COED-2 and COED-4, both produced from Utah coal, had higher freezing points than the COED fuels made from Western Kentucky coal. This was the case even though COED's 1 through 4 had similar distillation ranges. The Paraho shale oil sample was far above the JP-5 fuel freezing point spec of -51°F. The LERC in-situ shale samples also had very high freezing points, -16°F for the multistep product and -15°F for the single step material. Flash points were not available for these two shale fuels.

C. Combustion Properties - The smoke points of several alternate jet fuels are displayed in Figure 3 as a function of aromatics content. In addition, this graph presents the smoke point vs. % aromatic relationship for 29 CRC-AF petroleum-derived fuels (22). The general control of smoke point by aromatic content is apparent both for the petroleum-derived and the alternate fuels. Some fuels with low aromatic contents exhibit low smoke points, however, and do not fit the primary relationship. The four petroleum fuels which show this behavior possess high naphthene content, 80% or higher. COED-3 and COED-4, which have been derived by severe hydrogenation (3000 psig to afford a low aromatic content) of a highly aromatic syncrude (21),

should also contain high concentrations of naphthenes. Hence, the anomalous smoke point behavior shown, both by alternate and petroleum-derived jet fuels, can be explained on the basis that naphthenes influence this property if the aromatic content is low.

Smith (23) has suggested a formula for calculating the smoke point of kerosenes based on paraffin, naphthene and aromatic content but it is not useful for the fuels discussed in this paper. The broad definition of aromatic and naphthene is not adequate for combustion considerations. For instance, one mole/l of either butyl benzene or naphthalene would give about the same aromatic concentration by the specification test but the latter compound would have a much greater effect on the smoke point.

D. Stability - The thermal oxidation stability and gum forming tendencies of the alternate fuels are listed in Table II. COED-1 and COED-5 fail the 500°F thermal stability test by slight amounts but the Paraho shale oil material fails by 50°F. Further, this shale oil is the only fuel to fail the existent gum requirement of 7 mg/100 ml. The sulfur content of all of the alternate fuels is about the same and well below the 0.4% specification limit. Although jet fuel has no limit on nitrogen, the shale fuel is much higher in nitrogen than the other alternate and petroleum jet fuels.

Clay filtration of the shale jet fuel raised the breakpoint for thermal oxidation stability to 475°F but the existent gum remained high, 64 mg/100 ml, as did the nitrogen. Acid treatment (≈ 2 lb 98% H_2SO_4 /bbl) reduced the basic nitrogen to zero, enabled the thermal stability requirement to be met but did not greatly improve the gum formation. Distillation to a 90% recovery gave a product which passed both thermal stability and gum (1.2 mg/100 ml) tests. Basic nitrogen remained high, however. These results do not delineate the role of nitrogen in fuel stability and additional work will be needed to clarify the stability behavior of shale fuels.

It is noteworthy that severe hydrogenation to reduce the aromatic content of coal liquids (COED-1 to 3 and COED-2 to 4) significantly improved the thermal oxidation stability (to $>700^\circ F$).

E. n-Alkane Content - Since n-alkanes are likely to be related to the high freezing points of some of the alternate fuels, the concentration of these compounds was determined.

The saturate fractions were separated from the aromatics by pentane elation from activated silica gel (Davison Grade 923). Each saturate fraction was then analyzed by gas chromatography (GC) on a 300 ft. Apiezon L capillary column at 140°C. A sample of 0.1 microliter was split 100:1 ahead of the column and the helium flowrate through the column was 1.0 cc/min. This column, when operated under the described conditions, had an efficiency of 184,000 theoretical plates for n-tetradecane. A known amount (5.0 wt %) of n-octane was added as an internal standard and the weight % of each n-alkane was calculated by comparing electronic integrator counts to the octane count. Identification of the n-alkane peaks was made on a Hewlett-Packard 5982 GC-MS system using a 100 ft. OV-101 support coated open tubular column - temperature programmed from 100 to 160°C and with a helium flowrate of 3 cc/min. Corroborating identification came from matching GC retention times for fuel components on the Apiezon L column with standards on the same column.

The n-alkanes were the major peaks in most of the saturate fractions. The n-alkanes from nonane to hexadecane were found in most of the alternate fuels. In addition, small amounts of n-heptadecane were found in the shale fuels. The n-alkane concentrations are listed in Table III. The sum of the n-alkanes in the fuels decreases in the order: Paraho shale, LERC shales, petroleum, tar sands, Utah COED's, W. Ky. COED's. This order holds for individual n-alkanes in the middle

of the distillation range - C_{12} , C_{13} and C_{14} - but varies for smaller or larger compounds because of differences in initial boiling point or end point.

The total n -alkane concentration does not afford a significant relationship with freezing point. However, the freezing point does show some dependence on the amount of the larger hydrocarbons present in fuel samples. This is illustrated for n -hexadecane in Figure 4. The $\log (\% C_{16})$ vs. the reciprocal freeze point of the 11 fuels listed in Table II indicates a reasonable adherence to a solubility plot. This is remarkable in view of the different distillation ranges, the variation in aromatic/naphthene contents, and the neglect of other n -alkanes in this consideration.

The Paraho jet fuel was treated with urea to remove n -alkanes (24). The percent of the n -alkanes removed by this process and the amount remaining in the fuel are shown in Table IV. Overall, 47% of the n -alkanes (17% of the total fuel) were removed. The percent removed increased with molecular weight. The removed material was 98% n -alkanes with the remainder being identified by GC-MS as mostly 2-methyl alkanes and 1-alkenes. The stripped sample with an n - C_{16} content of 0.17%, had a freezing point of -54°F which places it close to the curve in Figure 4.

DISCUSSION

Suitable jet fuels can be made from any of the alternate energy sources - oil shale, tar sands or coal. However, refining processes may have to be modified from those used with petroleum crude and processing conditions may have to be more severe, particularly for oil shale and coal liquids. Since crudes from oil shale, tar sands and coal are closer in properties to the lower API gravity petroleum crudes, hydrocracking and delayed coking will be used extensively in producing military fuels from these alternate sources.

The jet fuel properties which are of greatest concern with the new fuels are the freezing point, combustion properties, and stability, both thermal oxidative and storage. Additional understanding is required on the effect of composition on these properties. Development of such information will aid in selecting or modifying refining processes to produce suitable fuels at reasonable costs. Techniques to remove nitrogen from shale oil and to convert n -alkanes to lower freezing compounds are needed. Cheaper hydrogenation processes must be developed for economical conversion of coal liquids to jet fuels with satisfactory heats of combustion.

The high concentrations of n -alkanes found in the shale oil samples affords clues on the nature of the organic material in shale. This information indicates that oil shale contains many long, straight chain components. When thermally stressed, as in retorting or coking, such constituents would yield smaller fragments which would also have straight chains (25). The major products would be n -alkanes and 1-alkenes. Since the latter hydrogenate to the former, n -alkane concentration could be considerable. It is interesting that the three shale jet fuels studied in this work were high in n -alkanes. This is in spite of differences in production, refining and hydrogenation processes.

Work will continue in relating composition to properties of the alternate jet fuels. This will include attention to non-specification properties and those properties which may be inherently different due to the origin of the base stock.

ACKNOWLEDGEMENT

The authors thank the Naval Air Systems Command for support to accomplish this research. The opinions expressed are the author's and do not necessarily reflect those of the U.S. Navy.

LITERATURE CITED

1. MIL-T-5624J, Turbine Fuel, Aviation, Grades JP-4 and JP-5, 30 Oct., 1973
2. C. R. Martell and L. C. Angello, "Hydrogen Content As a Measure of the Combustion Performance of Hydrocarbon Fuels", AFAPL-TR-72-103, Wright-Patterson Air Force Base, Ohio, May 1973.
3. E. Dimitroff, J. T. Gray, Jr., N. T. Meckel and R. D. Quillian, Jr., Seventh World Petroleum Congress, Individual Paper No. 47, Mexico City, Mexico, Apr. 2-9, 1967.
4. W. A. Affens and G. W. McLaren, J. Chem. & Eng. Data, 17, 482 (1972).
5. W. A. Affens, J. T. Leonard, G. W. McLaren and R. N. Hazlett, 172nd ACS Meeting, Division of Fuel Chemistry, this symposium.
6. Coordinating Research Council, "Evaluation of CRC Luminometer", New York, N.Y., June 1959.
7. R. M. Schirmer and E. W. Aldrich, "Microburner Studies of Flame Radiation as Related to Hydrocarbon Structure", Phillips Petroleum Company, Prog. Rpt. No. 4 on Navy BUWEPS Contract NOW63-0406-d, May 1964.
8. M. Smith, Aviation Fuels, Ch. 49, G. T. Foulis and Co., Ltd., Henley-on-Thames, England, 1970.
9. H. Ravner, C. Singleterry and R. N. Hazlett, "Aircraft Propulsion; Advanced Fuels and Lubricants R&D Goals - - 1970 to 1980," Naval Air Systems Command Committee Report, June 1971.
10. W. F. Taylor, I&EC Prod. R&D, 8, 375 (1969).
11. W. F. Taylor and T. J. Wallace, I&EC Prod. R&D, 7, 198 (1968).
12. W. F. Taylor, Paper 680733, SAE Aeronautic and Space Eng. Mtg., Los Angeles, CA. Oct. 1968.
13. F. G. Schwartz, M. L. Whisman, C. S. Albright and C. C. Ward, "Storage Stability of Gasoline," Bureau of Mines Bulletin 626, 1964.
14. J. Solash and R. F. Taylor, 172nd ACS Meeting, Division of Fuel Chemistry, this symposium.
15. H. Bortick, K. Kunchal, D. Switzer, R. Bowen and R. Edwards, "The Production and Refining of Crude Shale Oil into Military Fuels," Applied Systems Corp., Vienna, Va., Navy Contract N00014-75-C-0055, Aug. 1975.
16. C. M. Frost, R. E. Poulson and H. B. Jensen, 167th ACS Meeting, Division of Fuel Chemistry, 19, No. 2, 1974, p. 156.
17. R. E. Poulson, C. M. Frost and H. B. Jensen, 167th ACS Meeting, Division of Fuel Chemistry, 19, No. 2, 1974, p. 175.
18. C. M. Frost and R. E. Poulson, 169th ACS Meeting, Division of Fuel Chemistry, 20, No. 2, 1975, p. 176.
19. C. J. Nowack, "Endurance and Emission Tests of a T63-A-5A Engine Using a Tar Sands Derived JP-5," Naval Air Propulsion Test Center, Rpt. NAPTC-L-75-29, 23 June 1975.
20. R. D. Humphreys, Chem. Eng. Prog., 70(9), 66 (1974).
21. F. S. Eisen, "Preparation of Gas Turbine Engine Fuel From Synthetic Crude Oil Derived From Coal," Sun Oil Co. Final Rpt. on Navy Contract N00140-74-C-0568. Feb. 6, 1975.
22. Coordinating Research Council, Inc. Rpt. No. LD-148, "Fuel Inspection and Thermal Stability Data," 1 July 1965, New York.
23. M. Smith, Op. Cit., p. 85.
24. A. Hoppe, "Dewaxing with Urea," in Advances in Petroleum Chemistry and Refining, Vol. VIII, ed., John J. McKetta, John Wiley & Sons, New York, 1964.
25. B. M. Fabuss, J. O. Smith, and C. N. Satterfield, Advances in Petroleum Chemistry and Refining, Vol. IX, 157 (1964).

TABLE I

ALTERNATE FUEL SOURCES AND PROCESSES

<u>Fuel Source*</u>	<u>Method of Production</u>	<u>Method of Refining</u>	<u>Hydrotreat</u>	<u>Reference</u>
Shale-Paraho	Retort	Delayed Coking and Fractionation	Standard Pressure (Co-Mo)	15
Shale-LERC Multistep	In-Situ	Delayed Coking and Fractionation	1500 psig (Ni-Mo)	16,17
Shale-LERC Single Step	In-Situ	Fractionation after Hydrotreat	Total Oil 1500 psig (Ni-Mo)	18
Tar Sands-GCOS	Hot Water	Delayed Coking and Fractionation	Not Available	19,20
COED-1 FMC W.Ky. Coal	Pyrolysis	Fractionation	1500 psig (Ni-Mo)	21
COED-2 Utah Coal	Pyrolysis	Fractionation	1500 psig (Ni-Mo)	21
COED-3 W.Ky. Coal	Pyrolysis	Fractionation	1st stage 1500 psig (Ni-Mo) 2nd stage 3000 psig (Pt)	21
COED-4 Utah Coal				
COED-5 W.Ky. Coal	Pyrolysis	Fractionation	3000 psig (Ni-Mo)	21
Petroleum-A	Drilling	Not Available	Not Available	--
Petroleum-B	Drilling	Not Available	Not Available	--

* Paraho-Paraho Development Corp.; LERC-Laramie Energy Research Center; GCOS-Great Canadian Oil Sands, Ltd., FMC-Food Machinery and Chemical Co.

TABLE II

ALTERNATE FUEL PROPERTIES

Fuel	Thermal* Stability (°F)	Gum Existent (mg/100 ml)	Nitrogen (ppm)	Sulfur (wt. %)	Aromatics (percent)	Smoke Point (mm)	Viscosity at -30°F (cfs.)	Freezing Point (°F)	Heat of Combustion (BTU/lb)	Hydrogen (percent)
Shale-Paraho	450	81.7	680	0.05	26.0	22.0	frozen	-28	18,532	13.74
Shale-LERC Multistep	--	--	79	0.0001	23.7	--	--	-16	--	--
Shale-LERC Single Step	--	--	5	0.0005	21.3	--	--	-15	--	--
Tar Sands	Pass	1.2	--	0.01	19.3	20.0	12.85	-64	18,436	13.50
COED-1	495	0.0	40	0.05	24.8	17.0	23.69	-54	18,294	12.80
COED-2	510	0.1	42	0.04	24.1	17.0	22.94	-40	18,372	12.98
COED-3	>700	0.0	40	0.05	4.7	22.0	25.95	-58	18,383	13.34
COED-4	>700	0.1	43	0.03	6.1	22.0	23.03	-40	18,465	13.62
COED-5	485	0.1	37	0.03	24.1	18.0	9.04	<-70	18,282	12.81
Petroleum-A	Pass	<7	--	0.11	18.2	23.0	<16.5	-56	18,518	--
Petroleum-B	Pass	<7	--	<0.40	16.2	>19.0	<16.5	-59	--	--

*JFTOT Test, ASTM D3241, Pass indicates 500°F or higher

TABLE III

N-ALKANE CONTENT OF JET FUELS
FROM ALTERNATE SOURCESWEIGHT PERCENT

	C ₉	C ₁₀	C ₁₁	C ₁₂	C ₁₃	C ₁₄	C ₁₅	C ₁₆	C ₁₇	Σ
Shale Paraho	0.90	3.28	7.46	7.12	6.66	5.14	3.32	2.45	0.3*	36.33
Shale-LERC Multistep	0.002	0.11	3.11	6.08	5.81	4.26	3.48	2.46	0.6*	25.31
Shale-LERC Single Step		0.05	3.00	5.66	5.36	3.91	3.17	2.58	0.8*	23.73
Tar Sands-2	0.26	0.54	1.48	2.59	2.43	1.32	0.73	0.15	--	9.50
Coed-1		0.08	1.18	0.73	0.66	0.56	0.46	0.2	--	3.90
Coed-2		0.04	1.08	1.50	1.51	1.27	1.08	0.66	--	7.14
Coed-3	0.01	0.11	0.99	0.68	0.70	0.55	0.42	0.27	--	3.73
Coed-4		0.06	1.42	1.49	1.53	1.28	1.01	0.66	--	7.45
Coed-5	0.02	0.63	2.33	1.23	0.76	0.38	0.11	(0.02)	--	5.48
Petroleum-A	0.20	1.72	3.63	3.88	3.49	2.13	0.81	0.14	--	16.00
Petroleum-B	0.29	1.97	3.85	3.38	3.13	1.82	0.72	0.05	--	15.71

*C₁₇ peak broad, integration not accurate, not included in total

TABLE IV

RESULTS OF UREA STRIPPING OF PARAHIO
SHALE JET FUEL

<u>N-Alkane</u>	<u>Starting Material</u>	<u>Concentration (Percent) Product</u>	<u>N-Alkane Concentrate</u>	<u>Percent ** Removed</u>
Nonane	0.90	0.73	0.96	19
Decane	3.28	2.65	3.86	19
Undecane	7.46	5.43	11.54	27
Dodecane	7.12	4.66	16.50	35
Tridecane	6.66	3.33	19.13	50
Tetradecane	5.14	1.73	18.71	66
Pentadecane	3.32	0.67	15.16	80
Hexadecane	2.45	0.17	9.47	93
Heptadecane	0.3*	0.00	1.38	--
Total	36.33	19.37	98.0	

* Broad peak, integration not accurate, not included in total

** Based on comparison between product and starting material

NET HEAT OF COMBUSTION VS. PERCENT HYDROGEN

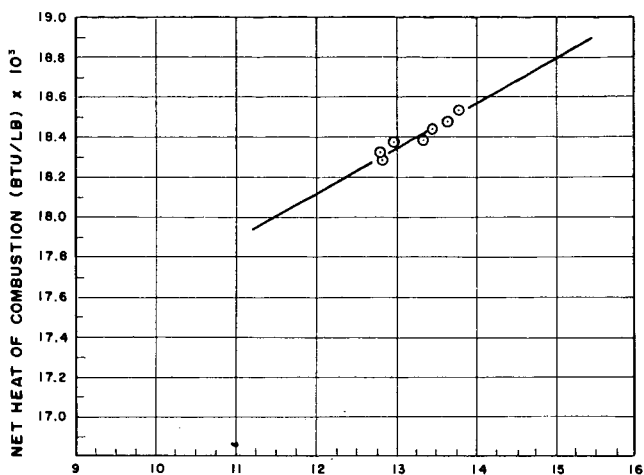


Figure 1 PERCENT HYDROGEN BY WEIGHT
 ○ JET FUELS FROM ALTERNATE ENERGY SOURCES

FREEZING POINT vs FLASH POINT

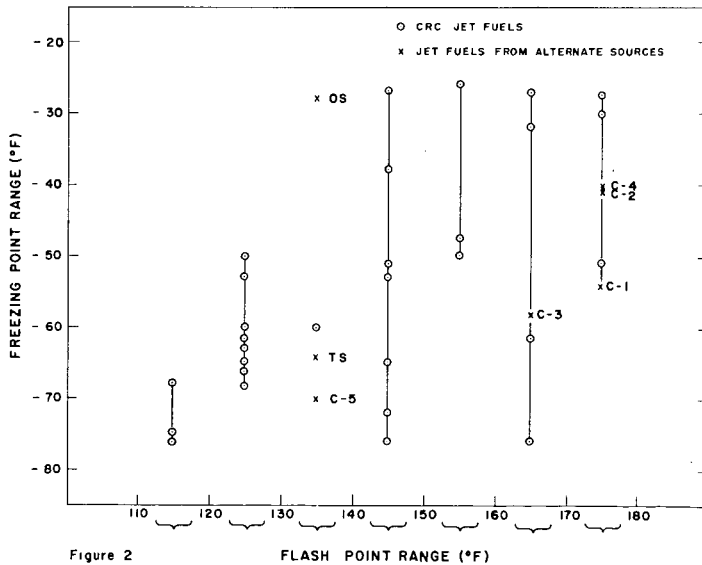


Figure 2 FLASH POINT RANGE (°F)

SMOKE POINT vs AROMATIC CONTENT

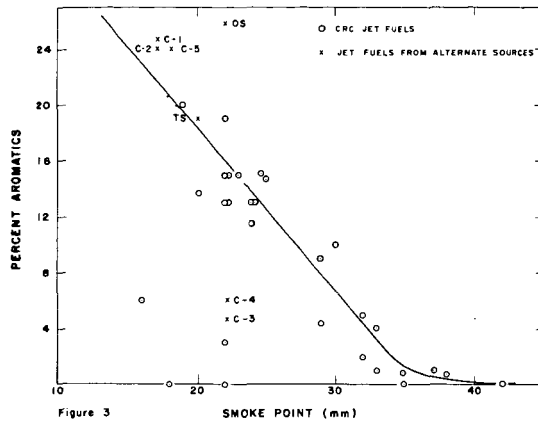


Figure 3

EFFECT OF N-HEXADECANE ON FREEZING POINT

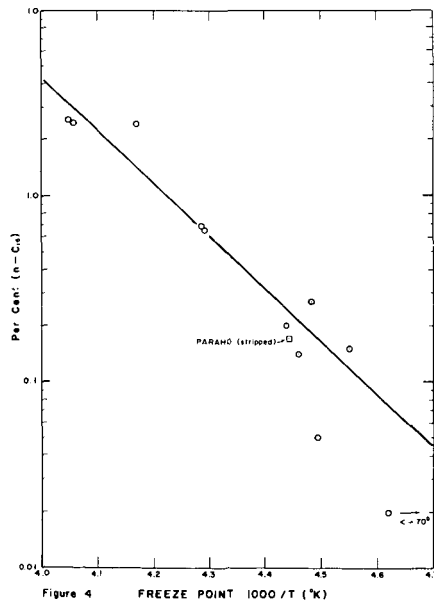


Figure 4